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03 Excretory Products and their Elimination

1. Introduction :

- Animals accumulate ammonia, urea, uric acid, carbon dioxide, water and ions like Na^+, K^+, Cl^-, phosphate, sulphate, etc., either by **metabolic activities** or by other means like **excess ingestion**. These substances have to be removed totally or partially.
- **Ammonia, urea** and **uric acid** are the major forms of nitrogenous wastes excreted by the animals. **Ammonia** is the **most toxic** form and requires large amount of water for its elimination, whereas **uric acid**, being the **least toxic**, can be removed with a minimum loss of water.

Characters	Type of animals		
	Ammonotelic	Ureotelic	Uricotelic
Excretory matter	Ammonia	Urea	Uric acid
Requirement of water for removal of waste	Very large	Less than ammonia	Least
Toxicity	Highest	Less than ammonia	Least
Examples	Aquatic insects Aquatic amphibia (Tadpoles)	Mammals, marine fishes, Terrestrial amphibia (frog)	Birds, Insects, Land Snails, many reptiles

- The process of excreting ammonia is **Ammonotelism**. Many bony fishes, aquatic amphibians and aquatic insects are **ammonotelic** in nature. Ammonia, as it is readily soluble, is generally excreted by **diffusion** across body surfaces or through gill surfaces (in fish) as ammonium ions. Kidneys do not play any significant role in its removal.
- Terrestrial adaptation necessitates the production of lesser toxic nitrogenous wastes like urea and uric acid for conservation of water. Mammals, many terrestrial amphibians and marine fishes mainly excrete urea are called **ureotelic** animals. Ammonia produced by metabolism is converted into urea in the liver of these animals and released into the blood which is filtered and excreted out by the kidneys. Some amount of urea may be retained in the kidney matrix of some of these animals to maintain a desired osmolarity.

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- Reptiles, birds, land snails and insects excrete nitrogenous wastes as uric acid in the form of pellet or paste with a **minimum loss of water** and are called **uricotelic** animals.

	Ammonotelic	Ureotelic	Uricotelic
Mechanism of excretion produced in the form of	By diffusion across body surfaces or through gill surfaces (in fish) as ammonium ions.	by metabolism ammonia is converted into urea in the liver and released into the blood which is filtered and excreted out by the kidneys.	Uric acid in the form of Paste or pellet

Earthworms excrete ammonia when sufficient water is available while they excrete urea instead of ammonia in terrestrial environment.

Excretion:
Removal of mainly nitrogenous substances from the body which are end product of metabolic activity.

OR

The process which is concerned with removal of nitrogenous waste materials (e.g., urea, uric acid, CO_2, ammonia, salts, excess water etc.) is termed excretion.

Homeostasis :
Maintenance of steady state **(Walter Cannon)**.
Homeostatic mechanism is important for normal life as they maintain condition within a range in which, the animal's metabolic processes can occur.

Ornithine Cycle :
Ammonia is converted into urea in the liver. Its also called urea cycle.

$$\underset{\text{(Ammonia)}}{2NH_3 + CO_2} \longrightarrow \underset{\text{(Urea)}}{NH_2CONH_2 + H_2O}$$

Excretory Organs in Animals :

Most of invertebrates = Simple tubular form
Vertebrates = Complex tubular organs called kidneys

Excretory organs	Protonephridia (Flame cells)	Nephridia	Malpighian tubules	Green glands or Antennal glands	Kidneys
Examples	– Platyhelminthes/ Flatworms (Planaria) – Rotifers – Some annelids – Cephalochordate (*Amphioxus*)	– Annelids (Earthworms)	– Most of the insects (Cockroaches)	Crustaceans (Prawn)	All vertebrates

Protonephridia are primarily concerned with ionic and fluid volume regulation, **i.e. osmoregulation.**

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BEGINNER'S BOX-1 INTRODUCTION AND EXCRETORY ORGAN

1. "Homeostasis" term was proposed by -
(1) Claude Bernard (2) Walter Cannon (3) Marcello Malpighi (4) Henle

2. Excretion in the from of uric acid and urates in birds is helpful in
(1) Conserving body heat (2) Eliminating excess water
(3) Conserving body water (4) Eliminating body water

3. Which one of following is the simplest excretory organs ?
(1) Alveoli (2) Flame cells (3) Nephridia (4) Kidney

4. In comparison to urea ammonia is
(1) Less toxic (2) Toxic (3) Highly toxic (4) None

5. Which excretory material is least toxic ?
(1) Ammonia (2) Urea (3) Uric acid (4) All are equally toxic

6. Uric acid is nitrogenous waste in
(1) Mammals and molluscs (2) Birds and lizards
(3) Frog and cartilaginous fishes (4) Insects and bony fishes

7. (a) The conversion of a protein waste, the ammonia into urea, occurs in
(b) Urea is synthesised in
(1) Kidneys (2) Lungs (3) Intestine (4) Liver

8. Animals accumulates waste like urea, uric acid, CO_2, H_2O, ions like Na^+, K^+, Cl^-, phosphate, sulphate, etc. by-
(1) Metabolic activities (2) Excess ingestion (3) Either 1 or 2 (4) Excretion

9. Order of toxicity among ammonia, urea and uric acid (from lower to higher) is -
(1) Uric acid < urea < ammonia (2) Uric acid < ammonia < urea
(3) Urea < uric acid < ammonia (4) Ammonia < urea < uric acid

10. Match the following columns –

Column I		Column II	
A.	Ammonotelic	1	Aquatic invertebrates
B.	Ureotelic	2	Reptiles
C.	Uricotelic	3	Birds
		4	Amphibians
		5	Mammals

(1) A-4, 5 ; B-3 ; C-1, 2 (2) A-1, 2 ; B-3 ; C-4, 5 (3) A-1 ; B-4, 5 ; C-2, 3 (4) A-2, 3 ; B-1 ; C-4, 5

11. Among ammonia, uric acid and urea, which one needs the least amount of water to excrete -
(1) Ammonia (2) Uric acid (3) Urea (4) Both 2 and 3

12. Ammonia produced by metabolism is converted into the ...A... in the ...B... in ureotelic and released into the blood, which is filtered and excreted out by ...C...
(1) A-Uric acid, B-Spleen, C-Kidney (2) A-Uric acid, B-Liver, C-Kidney
(3) A-Urea, B-Liver, C-Kidney (4) A-Urea, B-Spleen, C-Kidney

13. Match the following columns.

Column I (Organisms)		Column II (Excretory structures)	
A	Annelids	1	Simple tubular forms
B	Platyhelminthes and rotifers	2	Complex tubular forms (Kidneys)
C	Vertebrates	3	Protonephridia or flame cells
D	Most invertebrates	4	Nephridia

(1) A-1 ; B-2 ; C-3 ; D-4 (2) A-4 ; B-3 ; C-1 ; D-2
(3) A-1 ; B-2 ; C-4 ; D-3 (4) A-4 ; B-3 ; C-2 ; D-1

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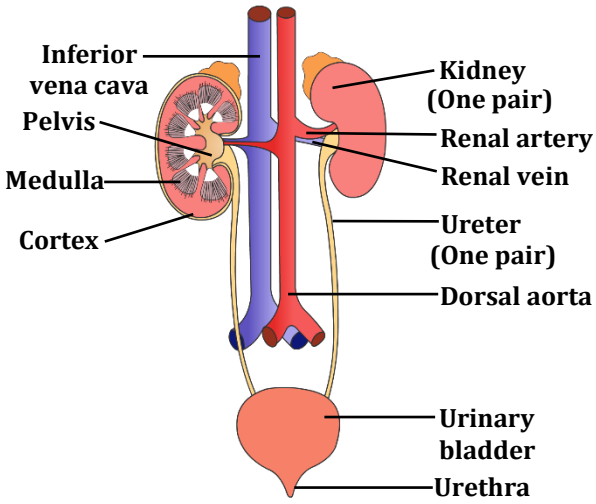
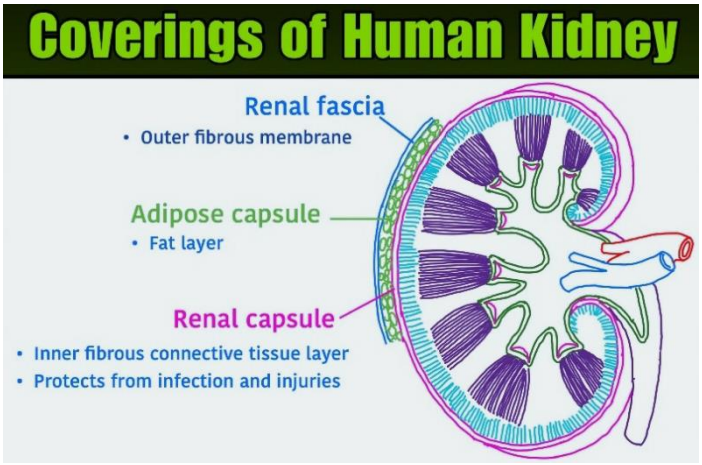
2. Human Excretory System :

Human excretory system consists of :

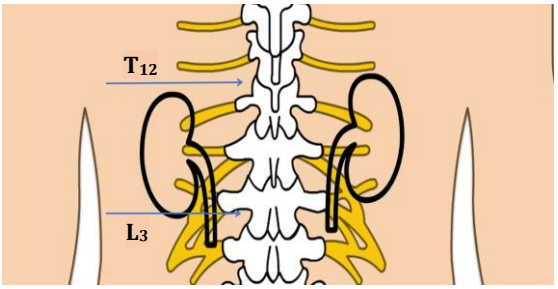
1. A pair of kidneys. 2. A pair of ureters. 3. A urinary bladder 4. A urethra



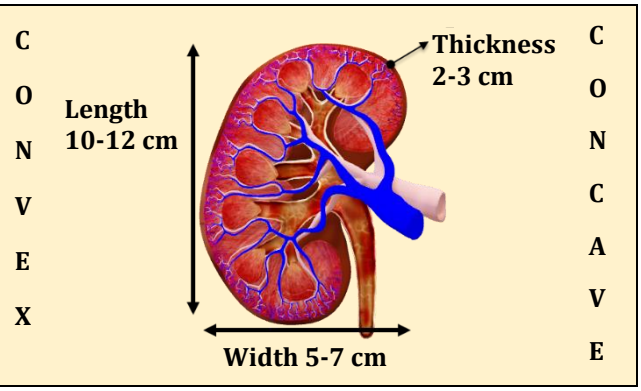


(A) Location of Kidneys :

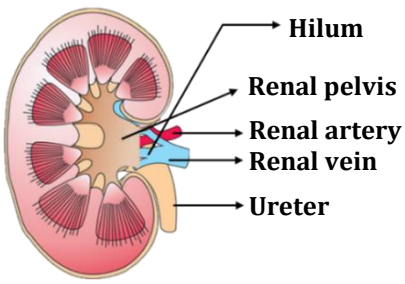
- Mammalian kidneys are bean shaped; reddish brown coloured with a **tough** fibrous connective tissue covering called **renal capsule**.
- Kidneys are located laterally on either side of vertebral column levels between the last thoracic (T_{12}) and third lumbar (L_3) vertebra close to the dorsal inner wall of the abdominal cavity.
- In humans, right kidney is at slightly lower level than left kidney, because of presence of liver in the right side of abdominal cavity.



Each kidney measures 10-12 cm in length,
5-7 cm in width and
2-3 cm in thickness,
weighing about 120-170 gm in an adult.
Lateral surfaces of kidney are convex while medial surfaces are concave



- Towards the centre of the inner concave surface of the kidney is a notch called Hilum **(Hilus renalis)**. Through this, renal artery and nerve enter while renal vein and ureter leave the kidney.
- Inner to the hilum is a broad funnel shaped space called the **renal pelvis**.



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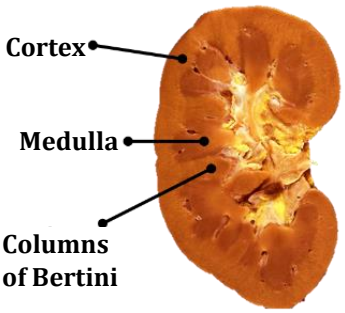
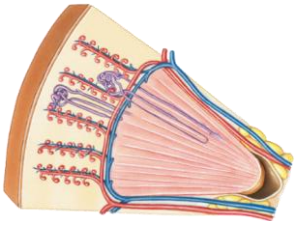
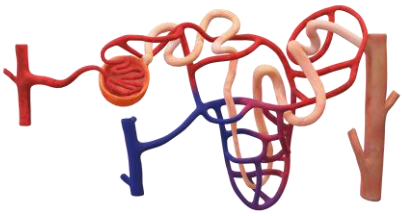
(B) Functions of Kidney :

- Excretion of metabolic waste and foreign chemicals.
- Regulation of body fluid osmolarity and electrolyte concentration.
- Regulation of acid base balance.
- Secretion of hormones like **Erythropoietin** and **Renin**.
- Regulation of arterial pressure.

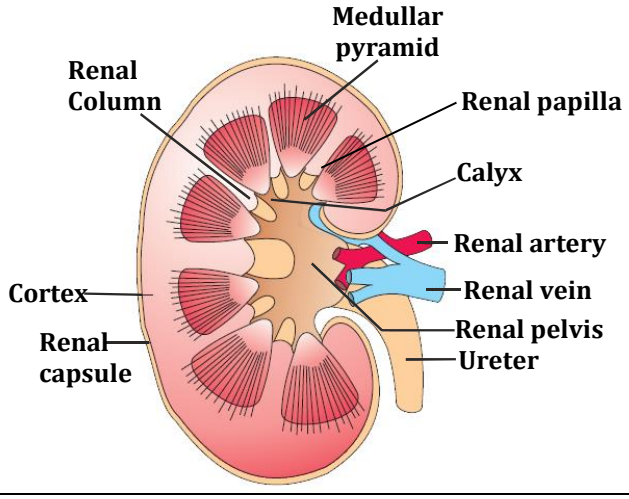
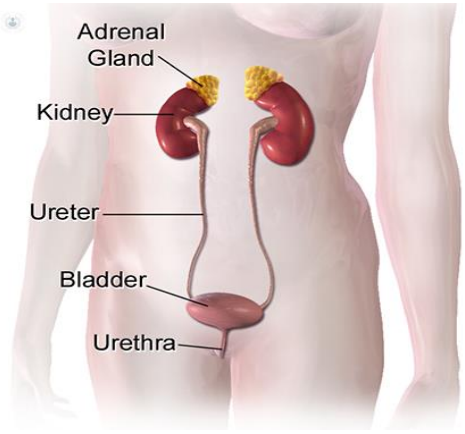
(C) Structure of Kidneys :

- Inside the kidney, there are two zones, an outer **cortex** and an inner **medulla**.
- The medulla is divided into a few conical masses **(medullary pyramids)** (8 to 12 in humans) projecting into the **calyces** (sing.: **calyx**).
- The cortex extends in between the medullary pyramids as renal columns called **columns of Bertini**.
- Each kidney has nearly **one million** complex tubular structures called **Nephrons** which are the **functional units.**



These nephrons are arranged in a radiating fashion within the renal pyramids	Complex tubular structures called Nephron
	

- Urine produced by each nephron empties into **collecting duct**.
- The collecting duct passes through a **papilla** into the **renal calyx** (Pleural - calyces).
- The renal calyces drain urine in the central cavity of renal pelvis.

Longitudinal section (Diagrammatic) of Kidney	Urinary System
	

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(D) Post Renal Urinary Tract :

(i) Ureter :

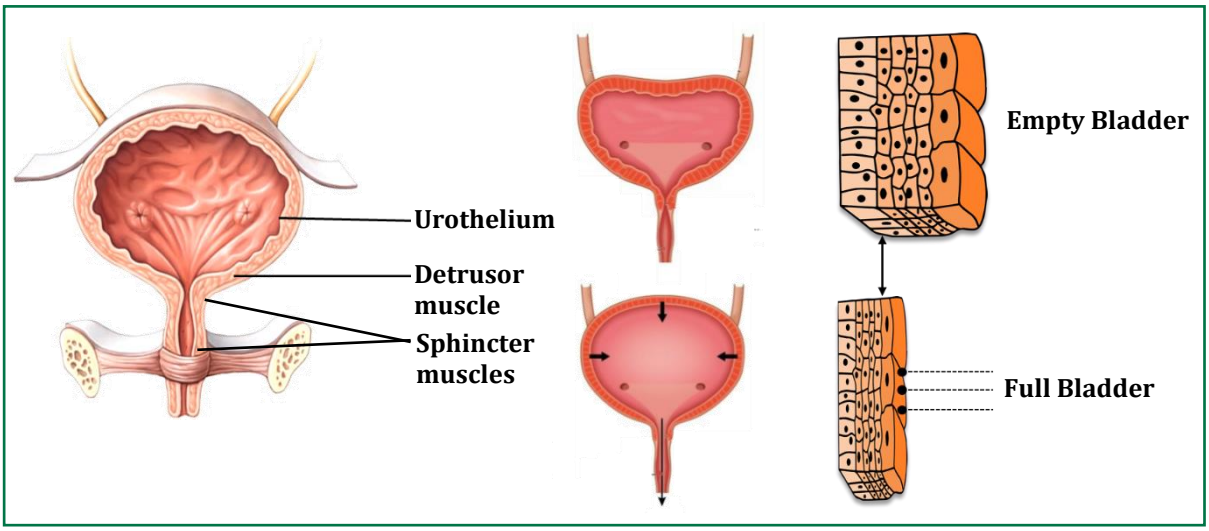
- Urine passes from the pelvis into the **ureter**. Both the ureters open through separate **oblique openings** into the **urinary bladder**. The obliquity of the openings prevents the backflow of urine.

(ii) Urinary bladder :

- Externally, the bladder is lined by **detrusor muscle**. It is **involuntary in nature** while internally the bladder is lined by **transitional epithelium or urothelium**.
- This epithelium has great capacity to expand so that large volume of urine can be stored. Opening of urinary bladder is controlled by sphincters made of circular muscles. In human two sphincters are present.

Inner = **Internal sphincter** (made up of involuntary muscle)
Outer = **External sphincter** (Voluntary muscle)

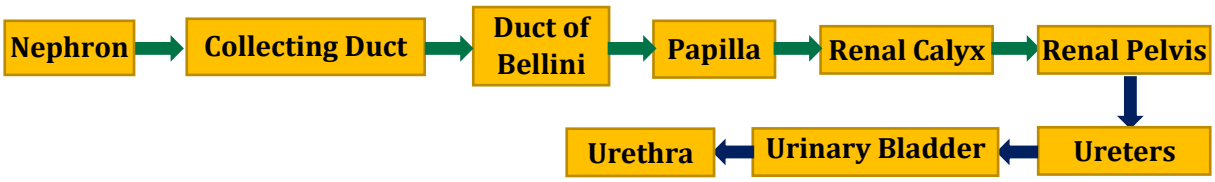
- These normally remain contracted and during micturition these relax to release urine.



(iii) Urethra :

- Urinary bladder opens into a membranous duct called **Urethra**.
- The urethra leads to end of the penis in males and into the vulva in females.

(iv) Flow of Urine:



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BEGINNER'S BOX-2

HUMAN KIDNEY AND POST RENAL URINARY TRACT

1. A notch present on the medial side of kidney is known as
(1) Ureter (2) Pelvis (3) Hilus (4) Pyramid

2. Inner wall of urinary bladder is composed of
(1) Unstriped squamous muscles (2) Striped muscles
(3) Stratified epithelium (4) Transitional epithelium

3. Pyramids in kidney of man are
(1) 4 (2) 6 (3) 7 (4) 12

4. In cortex area of kidney, all structures are found except :–
(1) Bowman capsule (2) D.C.T.
(3) Majority of collecting duct (4) Malpighian body

5. Columns of Bertini in the kidneys of mammals are formed as extensions of
(1) Cortex in medulla (2) Cortex in pelvis
(3) Medulla in pelvis (4) Pelvis in ureter

6. Functional & structural unit of kidney is -
(1) Nephron (2) Seminiferous tubule
(3) Acini (4) Alveoli

7. What will happen if one kidney is removed from the body of a human being ?
(1) Death due to poisoning
(2) Uraemia and death
(3) Stoppage of urination
(4) Nothing, the person will survive and remain normal kidney will become enlarged

8. External sphincter of male urethra in human being is found in :–
(1) Penile urethra (2) Membranous part
(3) Prostatic part (4) External urethral orifice.

9. Renal papilla is the part of :–
(1) Minor calyx (2) Pelvis (3) Pyramid (4) Major calyx

10. In human minor calyx number is :–
(1) Uncountable (2) 14 to 20
(3) Equal to pyramid number (4) Depends on major calyx number.

11. Inner to the hilum of the kidney, there is a broad funnel-shaped space called.
(1) Renal pelvis (2) Medulla (3) Cortex (4) Adrenal gland

12. The human each kidney has about -
(1) One million nephrons (2) Two million nephrons
(3) Three million nephrons (4) Ten million nephrons

13. In human, excretory system consists of -
I. Pair of kidneys II. One pair of ureters
III. Urinary bladder IV. Urethra
V. Skin VI. Lungs
VII. Liver
(1) I, II, III and IV (2) I, II, III and V
(3) I, II, III and VI (4) I, II, III, IV, V, VI and VII

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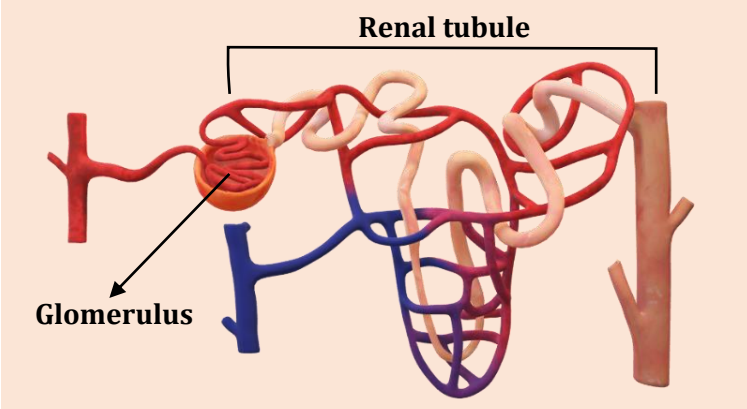
3. Structure of Nephron :

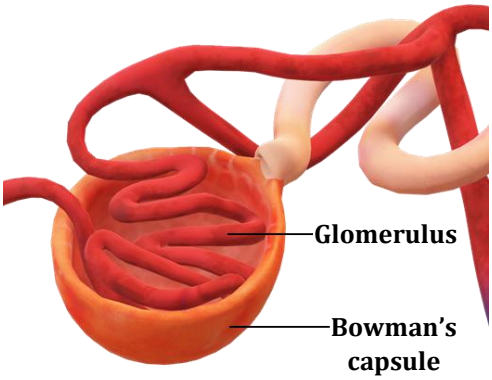
- Nephron is the **structural and functional unit** of kidney. It is an epithelial tube which is about **3 cm long** and **20-60 μm in diameter**.



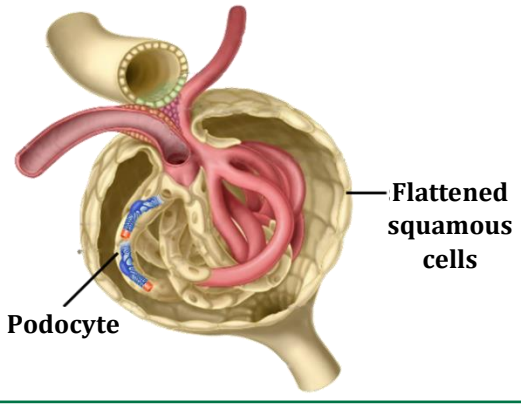
- Each nephron has two parts –
  - **(1) Glomerulus** – Is a tuft of capillaries formed by the afferent arteriole (a fine branch of renal artery). Blood from the glomerulus is carried away by an efferent arteriole.
  - **(2) Renal tubule** – Begins with a double walled cup-like structure called Bowman's capsule, which encloses the glomerulus.

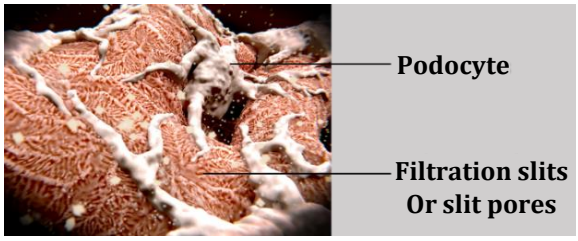
(A) Bowman's capsule :

- At the proximal or closed end the nephron is expanded and curved inwardly to form a double walled cup shaped Bowman's capsule.
- Within the Bowman's capsule a network or tuft of capillaries is present, called Glomerulus.
- **Malpighian body :** Glomerulus and its surrounding Bowman's capsule together forms Malpighian body or Renal corpuscle. It is responsible for first step of urine formation (Ultrafiltration).



- The outer wall of Bowman's capsule is composed of **flattened squamous cells**.
- The inner, invaginated wall that lines the concavity of Bowman's capsule is composed of a special type of cells called **Podocytes**. Which are arranged in an intricate manner so as to leave some minute spaces called **filtration slits or slit pores**.





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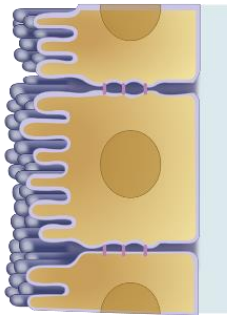
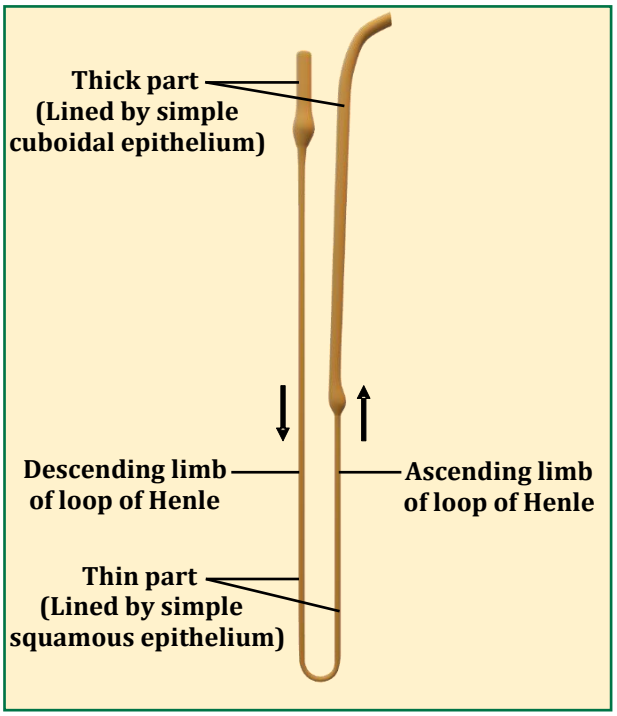
(B) Proximal Convoluted Tubule (PCT) :



- The tubule continues further to form a highly coiled network – proximal convoluted tubule (PCT).
- The epithelial cells of this region are specialised for transport of salts and other substances from the lumen to the interstitial fluid. It is lined by **simple cuboidal brush border epithelium.**
- The membranes of these cells facing the tubule lumen has numerous **microvilli** (finger like projections or Brush Borders) which increase the surface area.

(C) Loop of Henle :

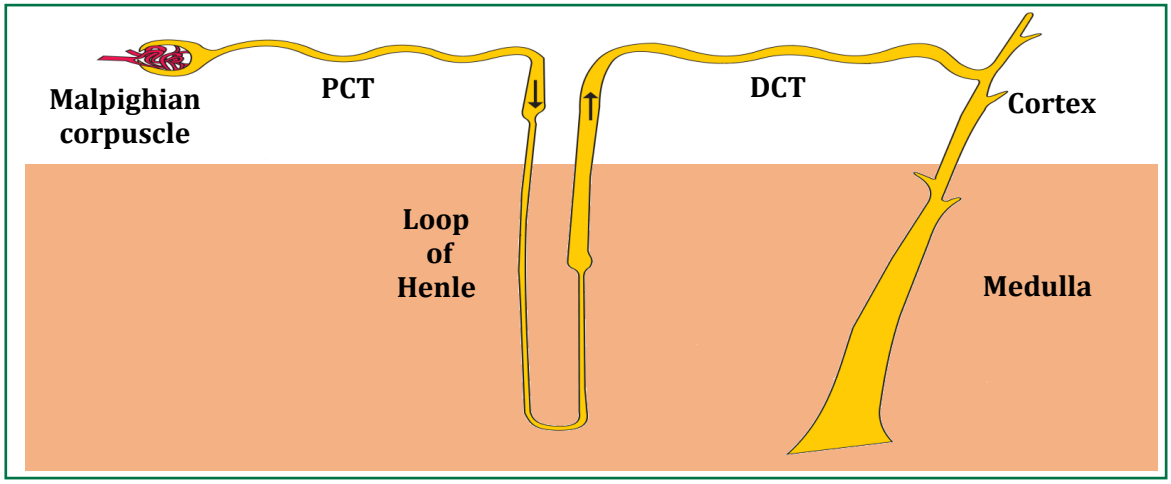
- A hairpin shaped Henle's loop is the next part of the tubule which has a descending and an ascending limb.



(D) Distal Convoluted Tubule (DCT) :

- The ascending limb of Henle's loop continues as another highly coiled tubular region called distal convoluted tubule. This is lined by **cuboidal epithelial cells**.
- The DCT of many nephrons open into a straight tube called **collecting duct**.
- Collecting ducts (present in medullary pyramids) are long tubules which traverse through the medulla in the pyramids. In the papilla of the medullary pyramid, several adjacent collecting ducts converge and open into a common short and thick **duct of Bellini** (present in papilla of medulla).
- All ducts of Bellini then open at the tip of the **papillae** into the **pelvis.**

Renal cortex – The Malpighian corpuscle, PCT & DCT of the nephrons are located here.
Renal medulla – Loop of Henle, collecting duct and ducts of Bellini are found in this region.



- The efferent arteriole emerging from the glomerulus forms a fine capillary network around the renal tubule called **peritubular capillaries**. A minute vessel of this network runs parallel to the Henle's loop forming a "U" shaped **Vasa recta**.

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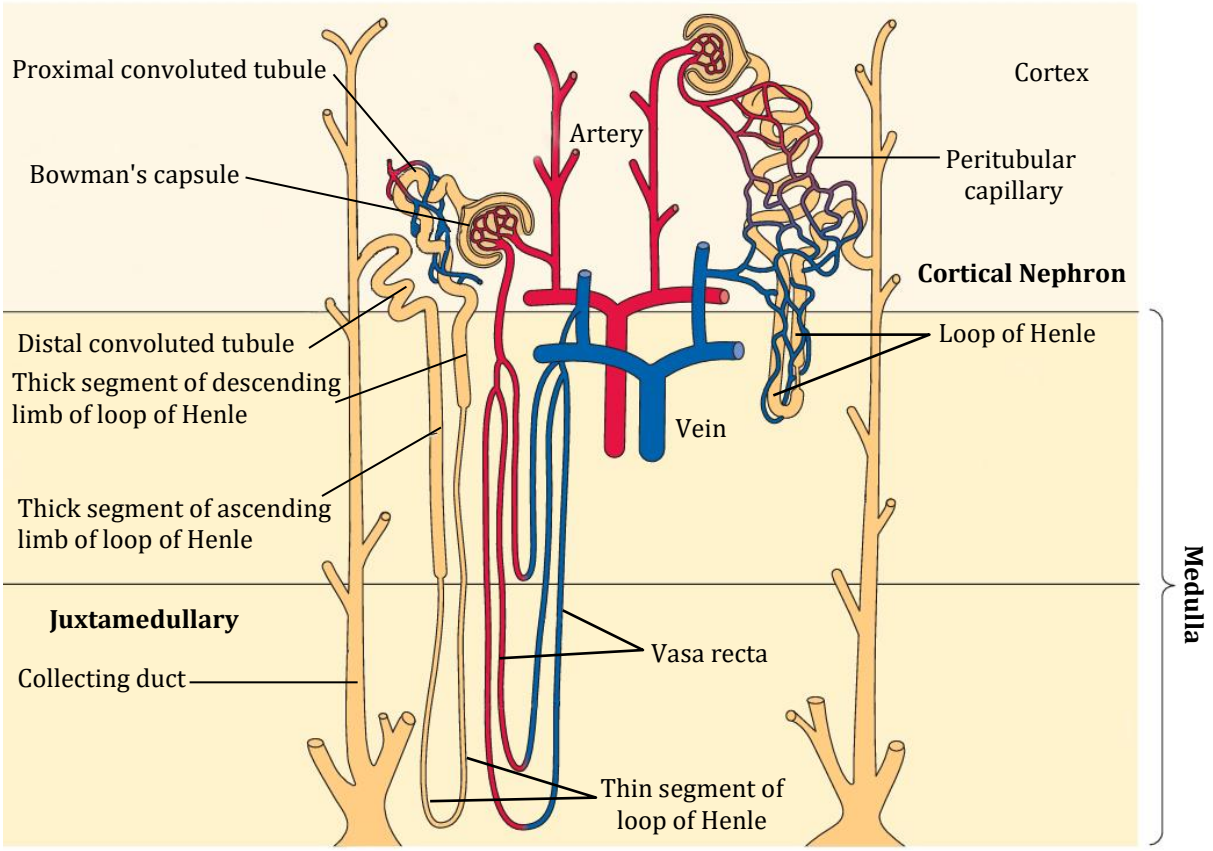
4. Types of Nephrons :

S.N.	Cortical nephrons	Juxtamedullary nephrons
1.	Constitute about 85% of total (75 - 85%)	Constitute about 15% of total (15 - 25%)
2.	Malpighian corpuscles are close to kidney surface	Malpighian corpuscles are located at the junction of cortex and medulla
3.	Here LOH mostly confined in cortex and a very small part of it runs in medulla	LOH of these nephrons is long, dipping deep down in medulla
4.	Peritubular capillary network present	Peritubular capillary network is not well developed
5.	Vasa recta is absent or highly reduced	Vasa recta present



In Cortical Nephrons:

- The efferent arterioles break up into dense **Peritubular network of capillaries** around their tubules.

In Juxtamedullary Nephrons:

- This vasa recta dips into the medulla or its pyramids surrounds the loops of Henle.
- Both peritubular capillaries of cortical nephrons and vasa recta of juxtamedullary nephrons lead into venules which join and rejoin to form small and large veins, all of which ultimately join to form renal vein.

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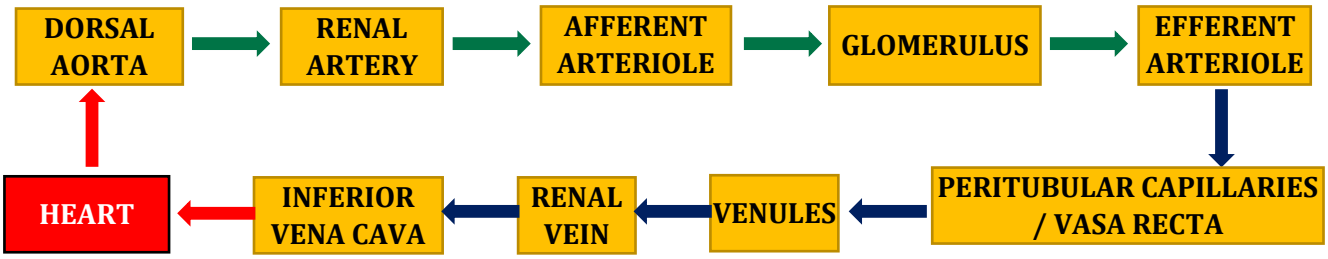
5. Blood Flow in Kidney :



- Each kidney receives its blood supply by a single **renal artery** from dorsal aorta, and is drained off by a single **renal vein**, which opens in the inferior vena cava. As the artery enters into the medulla after traversing through the hilum, it divides into a number of branches.
- These branches enter into renal cortex through the columns of Bertini and subdivide into **afferent arterioles** which form **glomerular capillaries.** These capillaries are drained, not by venules, but by **efferent arterioles.**
- Highest concentration of urea is found in hepatic vein. (because urea is synthesized in liver least concentration of urea is found in renal vein. (because urea is excreted through urine formed in kidney).

BEGINNER'S BOX-3 — NEPHRON AND BLOOD FLOW IN KIDNEY

1. Vasa recta are tubular capillaries around
(1) Posterior part of alimentary canal (2) PCT
(3) Loop of Henle (4) DCT

2. The blood vessel supplying blood into Bowman's capsule is
(1) Afferent arteriole (2) Efferent arteriole (3) Renal vein (4) Renal portal vein.

3. Loop of Henle present in
(1) Cortex (2) Medulla (3) Pelvis (4) Ureter

4. Brush border is characteristic of
(1) Neck of nephron (2) Collecting tube
(3) Proximal convoluted tubule (4) All the above

5. Part not belonging to uriniferous tubule (nephron) is -
(1) Glomerulus (2) Henle's loop
(3) Distal convoluted tubule (4) Collecting duct

6. Bowman's capsule is lined by
(1) Ciliated cuboidal epithelium (2) Squamous epithelium
(3) Nonciliated cuboidal epithelium (4) Non ciliated columnar epithelium

7. Podocyte are present in
(1) Afferent arteriole (2) Efferent arteriole
(3) Peritubular network (4) Bowman's capsule

8. The afferent and efferent vessels are
(1) Arterial in nature
(2) Venous in nature
(3) One is arterial and the other is venous
(4) None of the above

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9. Which of the following is correct ?
(1) Afferent arteriole is narrower than the efferent
(2) Efferent venule is narrower than vein
(3) Efferent arteriole is narrower than afferent arteriole
(4) None of these

10. Malpighian corpuscles present in
(1) Medulla (2) Cortex (3) Pelvis (4) Pyramid

11. The cells named podocytes occur in
(1) Inner wall of Bowman's capsule
(2) Outer wall of Bowman's capsule
(3) Large intestine
(4) Neck region of nephrons

12. In nephrons, the most part of loop of Henle's is found in the
(1) Medullary region of the kindney
(2) Cortical region of the kidney
(3) Both (1) and (2)
(4) Pelvis region of the kidney

13. In cortical nephrons,
(1) Loop of Henle is short (2) Loop of Henle is long
(3) The PCT is very long (4) The DCT is short

14. In juxta-medullary nephrons,
(1) Vasa recta is prominent
(2) Loop of Henle is long
(3) Loop of Henle runs deep into the medulla
(4) All of the above

15. In majority, juxta-medullary nephrons are found in the kidney of
(1) Kangaroo rat (2) Camel (3) Both 1 and 2 (4) Fishes

16. Each nephron has two parts, which are -
(1) Bowman's capsule and P C T
(2) Glomerulus and renal tubule
(3) Glomerulus and Bowman's capsule
(4) Bowman's capsule and renal tubule

17. Glomerulus is a tuft capillary formed by ...A... (A fine branch of renal artery). Blood from the glomerulus is carried away by an ...B... .
(1) A-Efferent arteriole, B-Afferent arteriole
(2) A-Efferent arteriole, B-Efferent arteriole
(3) A-Afferent arteriole, B-Afferent arteriole
(4) A-Afferent arteriole, B-Efferent arteriole

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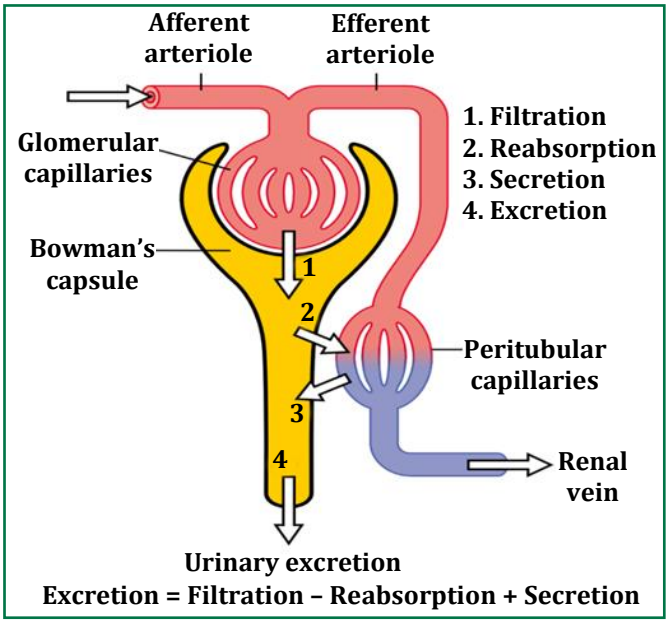
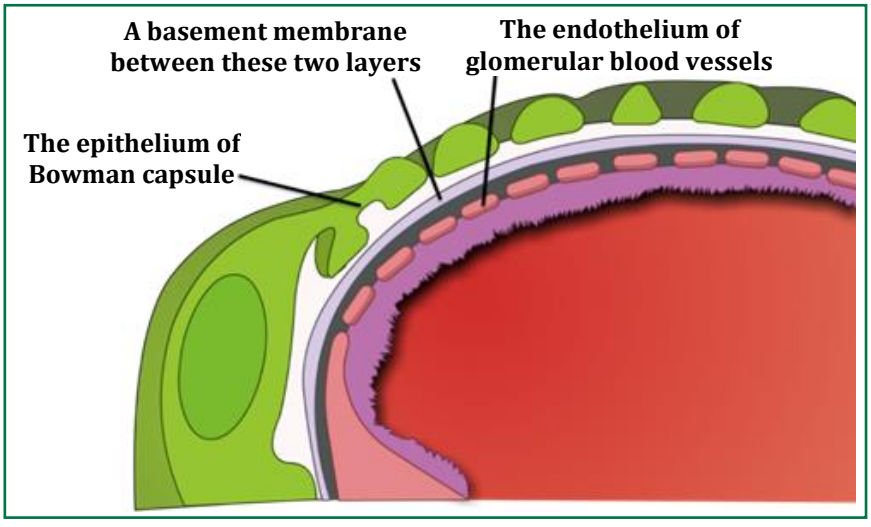
6. Mechanism of Urine Formation:

- The mechanism of urine formation involves three steps or processes :
  (i) Ultrafiltration or Glomerular filtration
  (ii) Selective tubular reabsorption
  (iii) Tubular secretion



(A) Ultrafiltration or Glomerular Filtration :

- The first step in urine formation is the filtration of blood, which is carried out by the glomerulus.
- This process occurs in the Malpighian corpuscle of the nephron.
- The **glomerular capsular membrane** (Filtration membrane) through which filtration of blood occur consists of three layers.
  (i) The endothelium of glomerular blood vessels.
  (ii) The epithelium of Bowman's capsule.
  (iii) A basement membrane between these two layers.


A basement membrane between these two layers
The endothelium of glomerular blood vessels
The epithelium of Bowman capsule

- The epithelial cells of Bowman capsule called podocytes are arranged in an intricate manner so as to leave some minute spaces called as filtration slits or slit pores.
- The blood is filtered so finely through these membranes that almost all the constituents of the plasma except the proteins pass onto the lumen of the Bowman's capsule. Therefore, it is considered as a process of **ultra- filtration**.
- The plasma fluid that filters out from glomerular capillaries is called as glomerular filtrate. **It is protein less plasma.**

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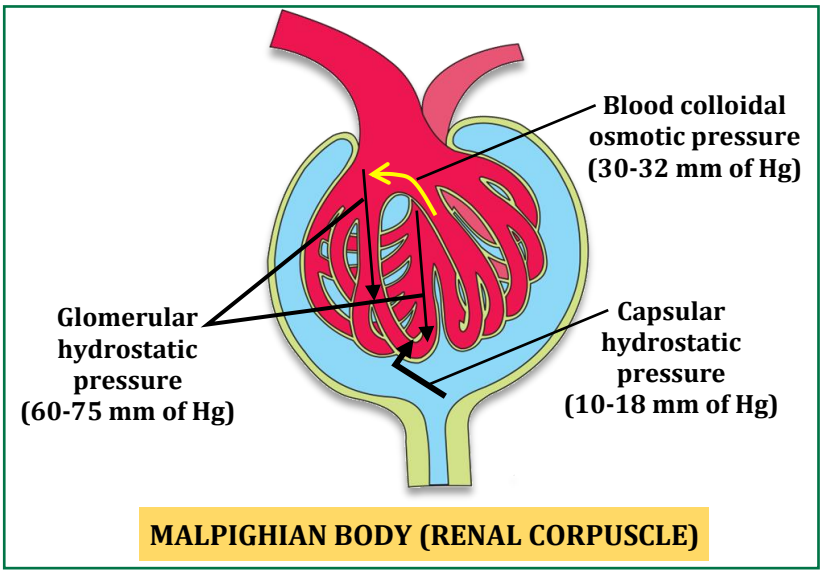
- About 20% of plasma fluid filters out into Bowman's capsule.
- The amount of the filtrate formed by the kidneys per minute is called **glomerular filtration rate (GFR)**. GFR in a healthy individual is approximately **125 ml/min i.e. 180 litres per day!!!**
- On an average 1100-1200 ml of blood is filtered by kidneys per minute (Renal blood flow) which constitute roughly 20-25% of the blood pumped by each ventricle of the heart in a minute (cardiac output) and of this blood about 650 ml is the blood plasma (55%). This 650 ml is called **Renal plasma flow (RPF).** About 20% of the blood plasma filtered by all nephrons of both kidney in a minute. It is 125 ml which called glomerular filtration rate (GFR).
- Filtration fraction = $\frac{GFR}{RPF} = \frac{125ml/min}{650ml/min} = \frac{1}{5}$

The effective filtration pressure that causes ultrafiltration is determined by three pressures:
(1) Glomerular hydrostatic pressure (GHP)
(2) Colloid osmotic pressure of blood (BCOP)
(3) Capsular hydrostatic pressure (CHP)

- **Glomerular hydrostatic pressure** is the blood pressure in glomerular capillaries, due to the difference is diameter of afferent and efferent arteriole.
- It is the main driving force to cause filtration. **(it is 60 to 75 mm Hg)**
- **Colloid osmotic pressure** is the osmotic pressure created in the blood of glomerular capillaries due to plasma proteins.
- It resists the filtration of fluid from the capillaries. **(it is 30 to 32 mm Hg)**
- **Capsular hydrostatic pressure** is the pressure caused by fluid (filtrate) that reaches into Bowman's capsule which resists filtration. **(It is about 10 to 18 mm Hg)**

Net filtration pressure :


Blood colloidal osmotic pressure (30-32 mm of Hg)
Glomerular hydrostatic pressure (60-75 mm of Hg)
Capsular hydrostatic pressure (10-18 mm of Hg)
MALPIGHIAN BODY (RENAL CORPUSCLE)

NFP = Glomerular hydrostatic pressure – [Blood colloidal osmotic pressure + capsular hydrostatic pressure]
NFP = GHP – [BCOP + CHP] = (75 or 60) – [32 + 18] mm of Hg
NFP = 10 to 25 mm Hg.

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(B) Selective Tubular Reabsorption:

- A comparison of the **volume of the filtrate** formed per day **(180 litres per day)** with that of the **urine released (1.5 litres)**, suggest that nearly 99% of the **filtrate has to be reabsorbed by the renal tubules**. This process is called **reabsorption**.
- The tubular epithelial cells in different segments of nephron perform this reabsorption either by both **active and passive mechanisms**. For example, substances like glucose, amino acid, Na^+ etc. in the filtrate reabsorbed actively whereas the nitrogenous wastes are absorbed by passive transport.
- Reabsorption of water also occurs passively in the initial segments of the nephron.

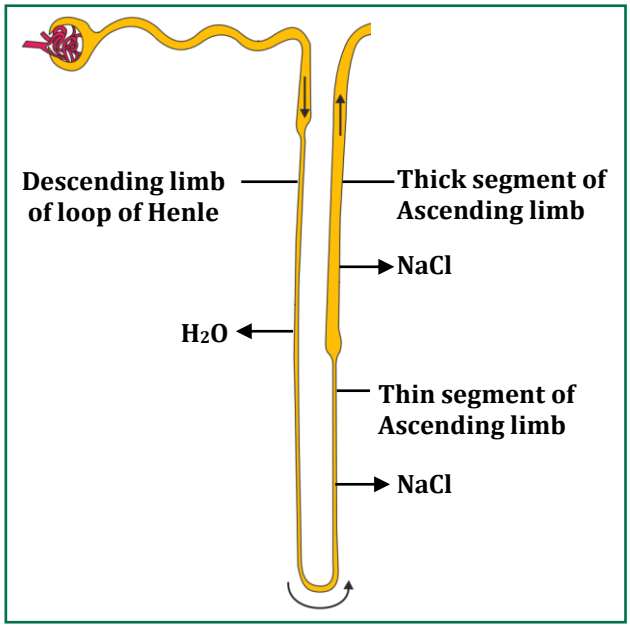
Function of the tubules :

Proximal convoluted tubule :

- Proximal Convoluted Tubule **PCT** is lined by simple cuboidal brush border epithelium which increases the surface area for reabsorption. Nearly **all of the essential nutrients** and 70-80% of electrolytes and water are reabsorbed by this segment.
- Glucose, Amino acids, Fatty acids are **completely** reabsorbed by active transport in PCT.
- Water & Cl^- are reabsorbed passively. Reabsorption in this segment is **maximum**.

Henle's loop:

- Reabsorption in this segment is minimum.
- Reabsorption is minimum in its ascending limb.
- However, this region plays a **significant role** in the **maintenance** of **high osmolarity of medullary interstitial fluid**.
- The **descending limb of loop of Henle** is **permeable to water** but almost **impermeable to electrolytes** so here water is reabsorbed passively. This limb concentrates the filtrate as it moves down.
- The **ascending limb loop of Henle** is **impermeable to water** but allows transport of electrolytes actively or passively. Therefore, as the concentrated filtrate pass upward, it gets diluted due to the passage of electrolytes in to the medullary fluid.



Distal convoluted tubule (DCT) :

- **Conditional reabsorption of Na^+ and water takes place** in this segment. In the presence of aldosterone hormone salts (Na^+) are reabsorbed actively and due to ADH water is reabsorbed passively. DCT is also capable of reabsorption of HCO_3^-.

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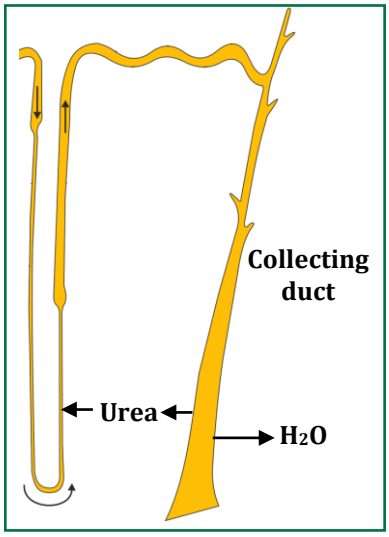
Collecting duct:

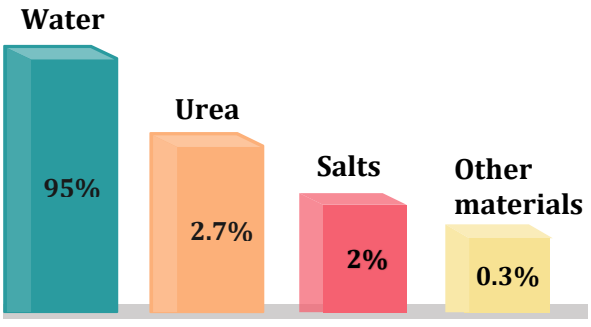


- This long duct extends from the cortex of the kidney to the inner parts of the medulla.
- Large amount of water could be reabsorbed from this region to produce a concentrated urine (in the presence of ADH).
- This segment allows passage of small amounts of urea into the medullary interstitium to keep up the osmolarity.
- The distal part of collecting duct is permeable to urea so small amount of urea is also reabsorbed from filtrate and it adds to the osmolarity of medullary interstitial.

(C) Tubular secretion:

- **During urine formation** the epithelial cells of renal tubules (tubular cells) secrete excretory substance like H^+, K^+ and ammonia (from the blood of peritubular capillary into the filtrate). This process is **tubular secretion.**
- It is an active process which occur in PCT, DCT & Collecting duct.
- **PCT** also helps to maintain the pH and ionic balance of the body fluids by selective secretion of hydrogen ions, ammonia, potassium ions, creatinine, uric acid, drugs, hippuric acid and pigments etc. into the filtrate and by absorption of HCO_3^- from it.
- **DCT** is also capable of reabsorption of HCO_3^- and selective secretion of hydrogen and potassium ions and NH_3 to maintain the pH and sodium-potassium balance in blood.
- **Collecting duct** plays a role in the maintenance of pH and ionic balance of blood by the selective secretion of H^+ and K^+ ions.
- Tubular secretion is **also an important step** in urine formation as it helps in the **maintenance of ionic** and **acid base balance** of body fluid.
- Tubular secretion is the only method of urine formation in the organisms having a glomerular kidney like marine teleost fish, desert amphibian.

Chemical composition of urine:



like Drugs, Hippuric acid, Uric acid, Vitamin-C, Dyes etc.

- An **adult human** excretes on an average **1-1.5 litres of urine per day.**
- Urine is **pale yellow** in colour due to **urochrome pigment**.
- On an average **25-30 gm of urea** is excreted out per day.
- Normal urine is **slightly acidic (pH = 6.0).**
- The volume of urine produced per day will increase on a **cold day**, due to ↓ADH secretion.

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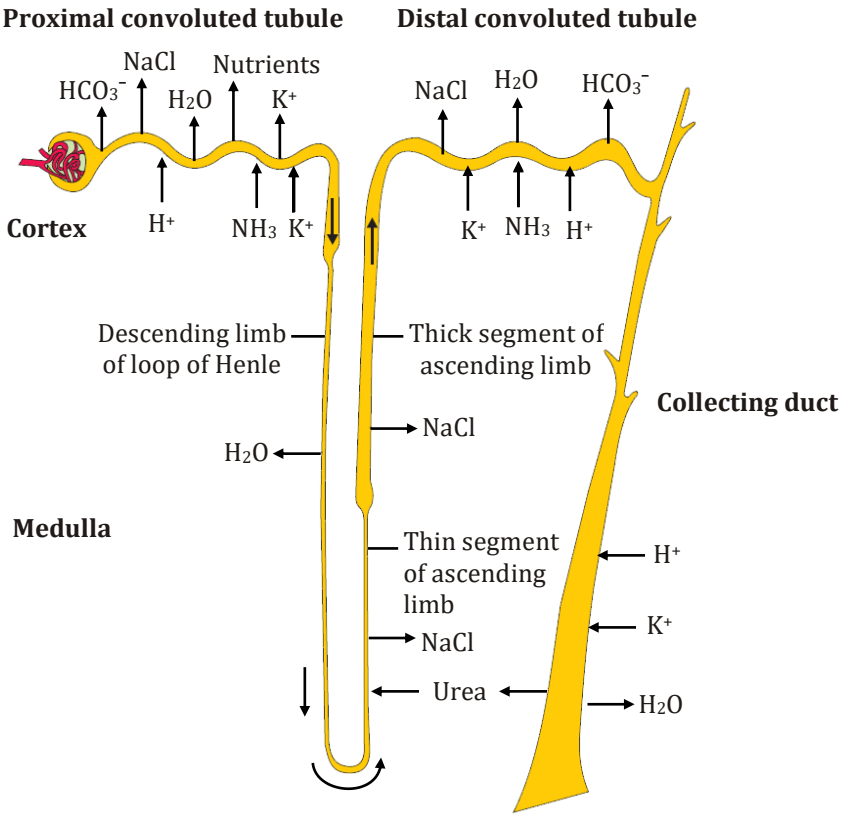

Reabsorption and secretion of major substances at different parts of the nephron (Arrows indicate direction of movement of materials.)

BEGINNER'S BOX-4 — PHYSIOLOGY OF URINE FORMATION

1. Blood Colloidal Osmotic Pressure is due to :–
(1) Platelets (2) RBC (3) WBC (4) Plasma proteins

2. Filtration membrane is formed by :-
(1) Endothelium of glomerular blood vessels (2) Epithelium of Bowman capsule
(3) Basement membrane (4) All of these

3. Which of the following is completely absorbed in P.C.T. ?
(1) Water (2) Salt (3) Na^+ (4) Glucose

4. Glomerular filtrate at the base of Henle's loop is
(1) Isotonic (2) Hypotonic (3) Hypertonic (4) Insoluble

5. The afferent arteriole diameter is more than efferent arteriole because:-
(1) It creates some resistance to flow blood
(2) It producing the back up of blood in the glomerulus
(3) It creates higher pressure in the glomerulus
(4) All of these

6. Which part of nephron is effected by aldosterone ?
(1) PCT (2) Late part of CT (3) DCT (4) Duct of Bellini

7. The filtrate from the glomerulus contains:-
(1) Urea and uric acid (2) Urea, uric acid and ammonia
(3) Urea, uric acid, ammonia and water (4) Urea, uric acid, glucose and water

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8. The filtrate from glomerulus contains:-
(1) Blood without cells and proteins (2) Plasma without sugar
(3) Blood with proteins but without cells (4) Blood without urea

9. Difference between glomerular filtrate and plasma is of:-
(1) Proteins (2) Potassium
(3) First is white where as later is yellow (4) First is yellow whereas later is white

10. The urine under normal conditions does not contain glucose because:-
(1) The normal blood sugar is fructose
(2) Glucose of blood is not filtered in the glomerulus
(3) Glucose in glomerular filtrate is completely reabsorbed in the uriniferous tubules
(4) Glucose in glomerular filtrate is converted into glycogen.

11. The reabsorption of glucose form the glomerular filtrate is due to:-
(1) High osmotic pressure of filtrate
(2) Passive diffusion
(3) Active transport across the wall of proximal convoluted part
(4) Filtration pressure exerted on the fluids in the loop of Henle

12. One is found in blood not in Nephric filtrate:-
(1) Urea (2) Glucose (3) Amino acids (4) Globulin

13. One of the following is impermeable to H_2O normally:-
(1) PCT (2) Ascending limb of loop of Henle
(3) Descending limb of loop of Henle (4) All

14. The yellow colour of urine of vertebrates is due to:-
(1) Cholesterol (2) Urochrome (3) Urinode (4) Urea

15. Which blood vessel contains the least amount of urea ?
(1) Hepatic vein (2) Renal vein
(3) Hepatic portal vein (4) Renal artery

16. Filtration in Malpighian body of the nephrons involves:-
(1) One layer (2) Two layer (3) Three layer (4) Four layer

17. Podocytes are present on the :-
(1) Endothelial cells of the glomerulus (2) Endothelial cells of the Bowman's capsule
(3) Epithelium cells of the Bowman's capsule (4) Epithelium cells of the glomerulus

18. Ultrafiltrate generated by the glomerulus is having all the constituent of the blood plasma except:-
(1) Protein (2) RBC (3) WBC (4) All of these

19. GFR (Glomerular Filtration Rate) is the amount of filtrate formed by the kidney per:-
(1) Hour (2) Second (3) Minute (4) 10 seconds

20. JGA (Juxta Glomerular Apparatus), a sensitive region, which regulates the glomerular filtration rate is present near the :-
(1) DCT and PCT (2) DCT and efferent arteriole
(3) DCT and afferent arteriole (4) Loop of henle's and DCT

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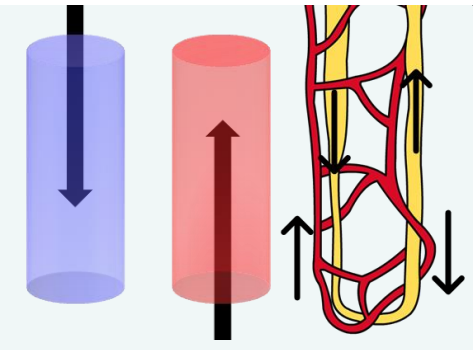
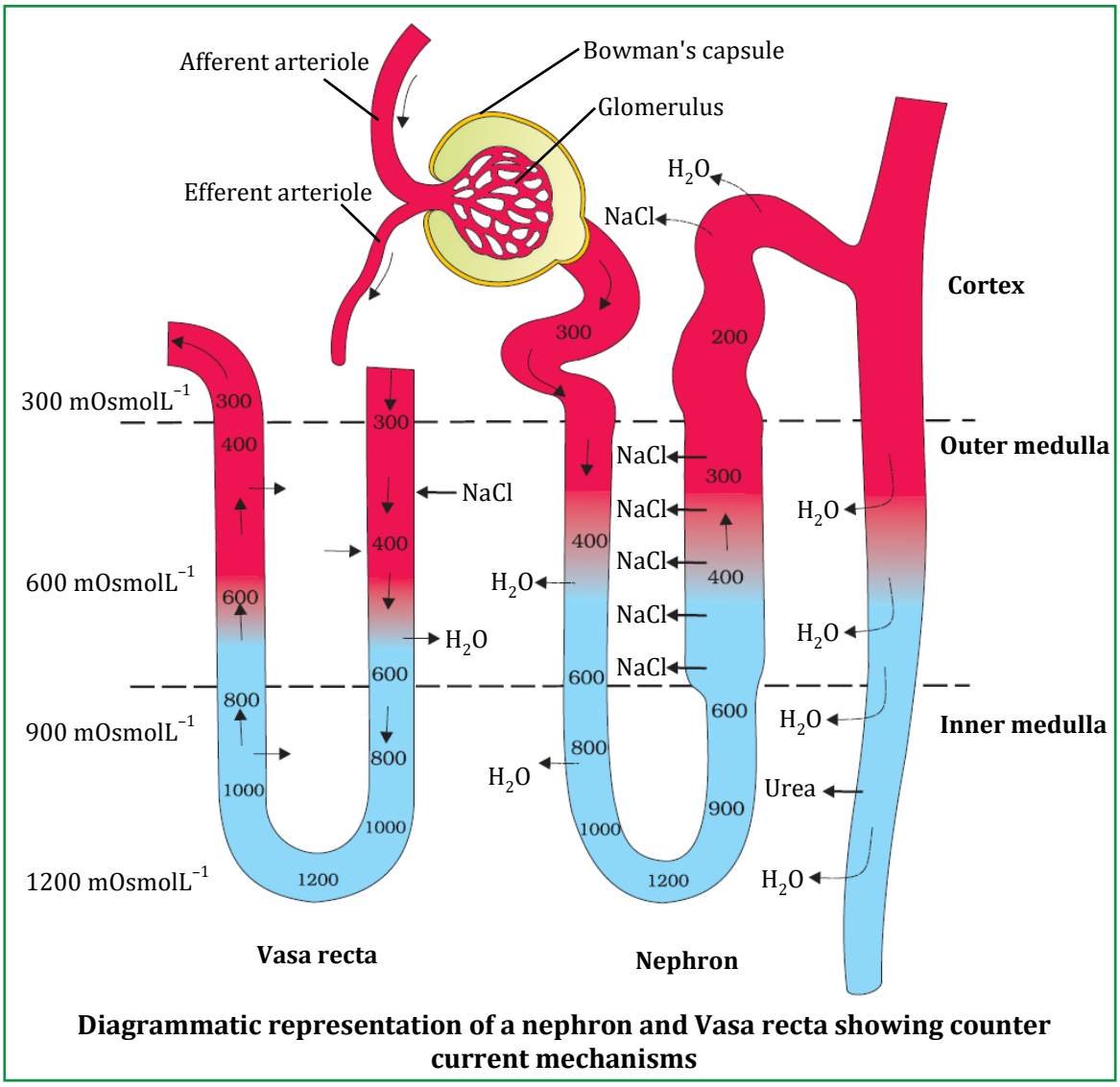
7. Mechanism of Concentration of the Filtrate (Counter Current Mechanism) :



- Mammals have the ability to produce a concentrated urine. The **Henle's loop** and **vasa recta** play a significant role in this.
- The flow of filtrate in the **two limbs of Henle's loop** is in **opposite directions** and thus forms a **counter current**. The flow of blood through the two limbs of vasa recta is also in a **counter current pattern**.
- The proximity between the Henle's loop and vasa recta, as well as the counter current in them help in maintaining an increasing osmolarity towards the inner medullary interstitium, i.e., from **300 mOsmolL^{-1}** in the cortex to about **1200 mOsmolL^{-1}** in the inner medulla. **This gradient is mainly caused by NaCl and urea.**
- **NaCl** is transported by the ascending limb of Henle's loop which is exchanged with the descending limb of vasa recta. NaCl is returned to the interstitium by ascending part of vasa recta.



Diagrammatic representation of a nephron and Vasa recta showing counter current mechanisms

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- Similarly, **small amounts of urea** enter the thin segment of the ascending limb of Henle's loop which is transported back to the interstitium by the collecting tubule.
- This special arrangement of Henle's loop and vasa recta is called the **counter current mechanism**. This mechanism helps to maintain a concentration gradient in the **medullary interstitium**.
- Presence of such interstitial gradient helps in an easy passage of water from collecting tubule. As the filtrate flow down in the collecting tubule more and more water move out of the tubule by osmosis which makes filtrate hypertonic to blood. Human kidney can produce **urine nearly four times concentrated** than the initial filtrate formed.

8. Regulation of Kidney Function :

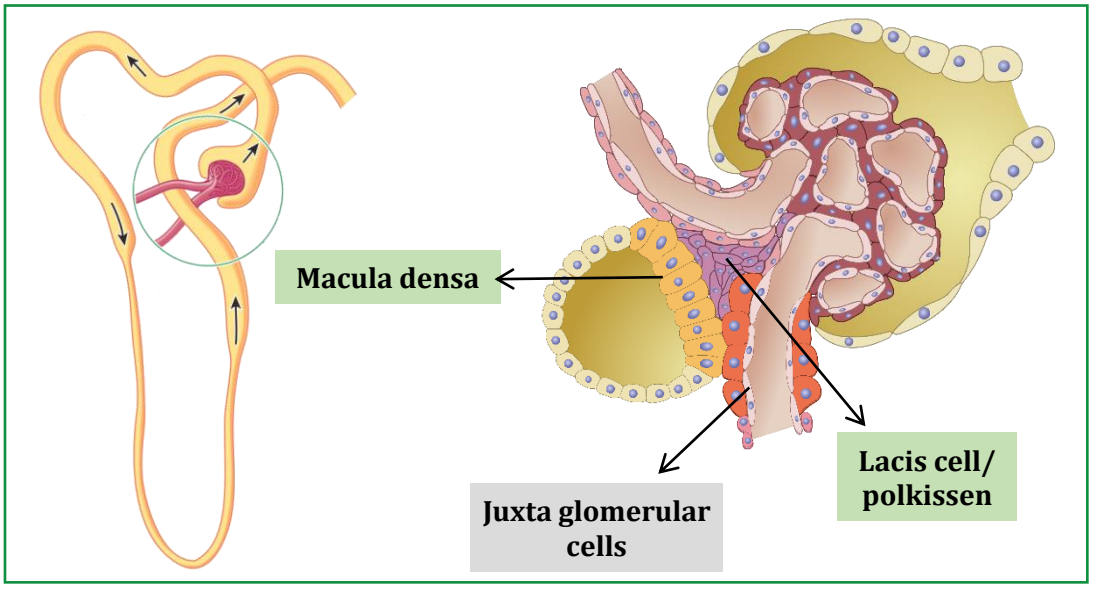
(A) Juxtaglomerular Apparatus (JGA) :

It consist of:- Juxtaglomerular cells + Macula densa + Lacis / Polkissen / Mesangial cell.

- JGA is a special sensitive region formed by cellular modifications in the DCT and the afferent arteriole at the location of their contact.
- It is built-in location for regulation of GFR.
- Fall in GFR can activate the JG cells to release renin which can stimulate the glomerular blood flow and thereby the GFR back to normal.

(i) **Juxtaglomerular cells :** The smooth muscle cells of the wall of both arterioles where it comes in contact with DCT are swollen and contain dark granules of inactive renin. These are called juxtaglomerular cells.

(ii) **Macula densa :** The cells of DCT epithelium in contact with the arteriolar wall are denser then other epithelial cells. These are collectively called as macula densa.



(B) Renin Angiotensinogen Aldosterone System:

- The functioning of the kidneys is efficiently monitored and regulated by **hormonal feedback mechanisms** involving the **hypothalamus, JGA** and to a certain extent, the **heart**.
- **Osmoreceptors** in the body are activated by changes in–

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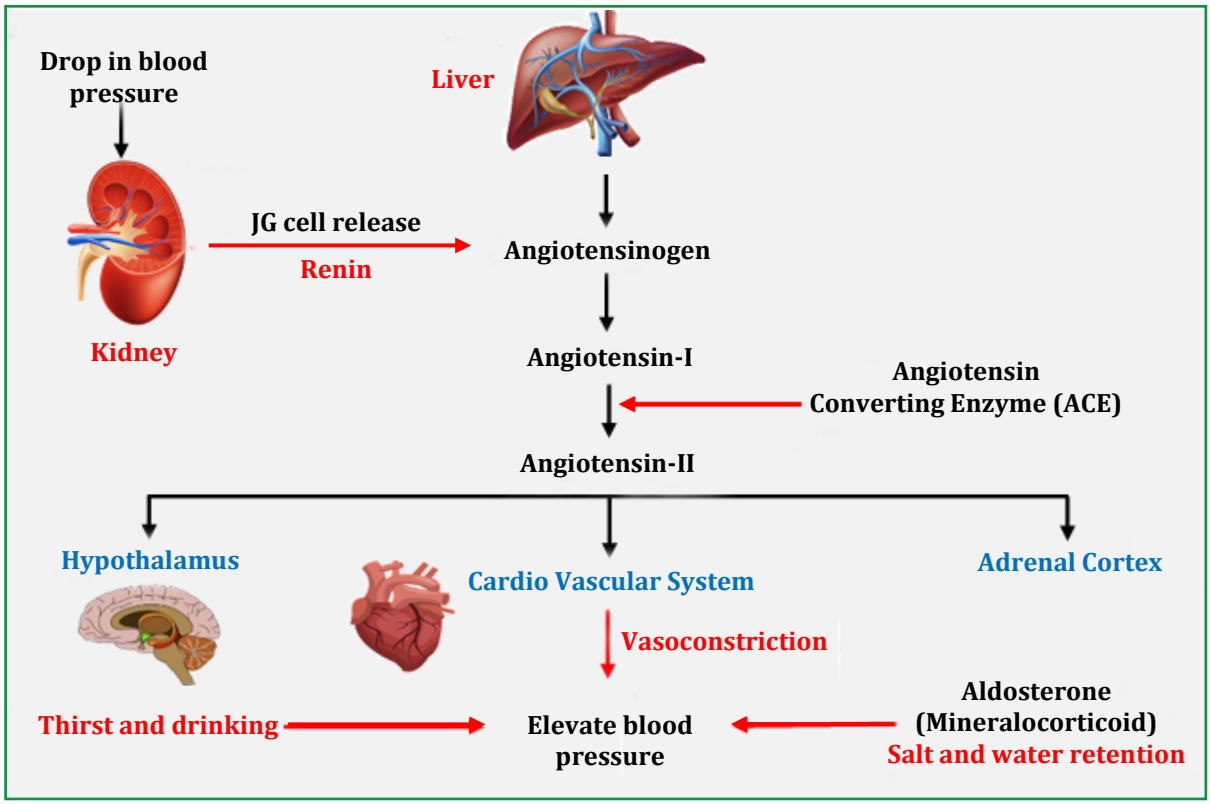
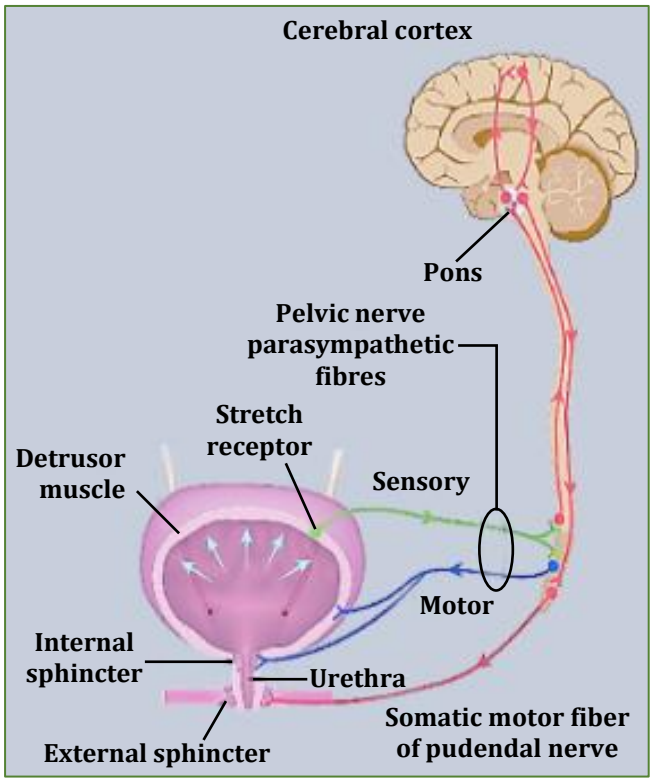
(i) Blood volume
(ii) Body fluid volume
(iii) Ionic concentration

- An **excessive loss of fluid from the body** can **activate these receptors** which stimulate the hypothalamus to release **antidiuretic hormone (ADH)** or **vasopressin** from the neurohypophysis. ADH facilitates water reabsorption from latter parts of the tubule, thereby **preventing diuresis**.
- An **increase in body fluid volume** can **switch off the osmoreceptors** and suppress the ADH release to complete the feedback.
- ADH can also affect the kidney function by its **constrictory effects on blood vessels**. This causes an increase in blood pressure. An increase in blood pressure can increase the glomerular blood flow and thereby the GFR.
- The **JGA** plays a complex regulatory role.
- **A fall in glomerular blood flow/glomerular blood pressure/GFR** can activate the **JG cells** to release **renin** which converts angiotensinogen in blood to angiotensin I and further to angiotensin II.
- **Angiotensin II**, being a **powerful vasoconstrictor**, increases the glomerular blood pressure and thereby GFR. **Angiotensin II** also activates the **adrenal cortex** to release Aldosterone.
- Aldosterone causes reabsorption of Na^+ and water from the distal parts of the tubule.



- This also leads to an increase in blood pressure and GFR. This complex mechanism is generally known as the **Renin-Angiotensin** mechanism.
- **An increase** in **blood flow to the atria of the heart** can cause the release of **Atrial Natriuretic Factor** (ANF). ANF can cause vasodilation (dilation of blood vessels) and thereby decrease the blood pressure. ANF mechanism, therefore, acts as a check on the renin-angiotensin mechanism.

9. Micturition :



- Urine formed by the nephrons is ultimately carried to the urinary bladder where it is stored **till a voluntary signal** is given by the **central nervous system (CNS)**.
- This signal is initiated by the **stretching of the urinary bladder** as it **gets filled** with urine.
- In response, the **stretch receptors** on the walls of the bladder send signals to the CNS.
- The CNS passes on motor messages to initiate the **contraction of smooth muscles** of the **bladder** and simultaneous **relaxation of the urethral sphincter** causing the release of urine.
- The process of release of urine is called **micturition** and the neural mechanisms causing it is called the **micturition reflex**.
- An adult human excretes, on an average, **1 to 1.5 litres** of urine per day.
- The urine formed is a **light yellow** coloured watery fluid.
- Urine is slightly **acidic (pH-6.0)** and has a characteristic odour.
- On an average, **25-30 gm of urea** is excreted out per day.
- **Various conditions can affect the characteristics of urine.**
- Analysis of urine helps in clinical diagnosis of many metabolic disorders as well as malfunctioning of the kidney.
- For example, **presence of glucose (Glycosuria)** and **ketone bodies (Ketonuria)** in urine are indicative of **diabetes mellitus**.

10. Role of other Organs in Excretion :

(A) Lungs :

- Our lungs remove large amounts of CO_2 (approximately 200mL/minute) and also significant quantities of water every day (400ml of water per day in normal resting condition).
- Different volatile materials are also readily eliminated through the lungs.

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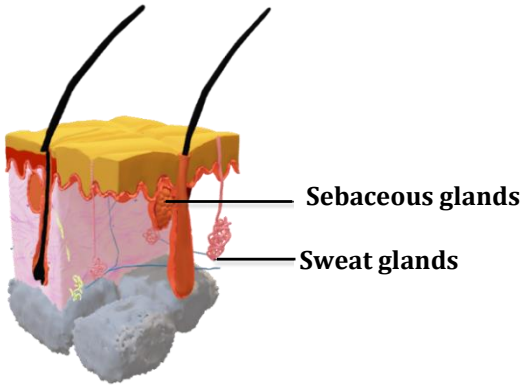
(B) Skin :

- Human possess two types of glands in skin:
  (i) Sweat glands (Sudorific glands)
  (ii) Sebaceous glands (Oil glands)
- The sweat and sebaceous glands in the skin can eliminate certain substances through their secretions.
- **Sweat** produced by the **sweat glands** is a watery fluid containing NaCl, small amounts of urea, lactic acid, etc. Though the **primary function of sweat** is to facilitate a **cooling effect on the body surface**, it also helps in the removal of some of the wastes mentioned above.



- **Sebaceous glands** eliminate certain substances like sterols, hydrocarbons and waxes through **sebum**. This secretion provides a protective **oily covering** for the skin.

(C) Liver :

- **Liver**, the **largest gland in our body**.
- Liver secretes **bile-containing** substances like **bilirubin, biliverdin, cholesterol**, degraded steroid hormones, vitamins and drugs.
- Most of these substances ultimately pass out along with digestive wastes.

11. Disorders of the Excretory System :

(i) **Uremia :** Presence of excess urea in blood. Malfunctioning of kidneys can lead to accumulation of urea in blood, a condition called uremia, which is highly harmful and may lead to kidney failure.

(ii) **Renal failure :** It is a syndrome characterised by renal dysfunction, oliguria, anuria, sudden rise in metabolic waste products like urea & creatinine in blood (Uremia). It is either of **acute** (sudden onset) or **chronic** (slow onset) **nature**.
Kidney transplantation is the ultimate method in the correction of renal failures (kidney failure). A functioning kidney is used in transplantation from a donor, **preferably a close relative, to minimise its chances of rejection** by the immune system of the host. Modern clinical procedures have increased the success rate of such a complicated technique.

(iii) **Renal calculi (Urolithiasis):** Formation of stone within kidney. These calculi are made of calcium phosphate, uric acid., cystine or **calcium oxalate**.

(iv) **Glomerulonephritis:** It is a disease where due to infection or injury in the basement membrane, the inflammation of glomerulus progressively leads to renal failure and death.

(v) **Oligouria :-** Less production of urine

(vi) **Anuria :-** No production of urine

(vii) **Polyuria :-** Excessive production of urine. More urine formation takes place due to less secretion of ADH. Due to less secretion of ADH, the amount of water increases in the urine. So, the patient feels thirsty again and again. This disease is called **Diabetes-insipidus**.

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(vii) **Glycosuria :-** Excretion of Glucose through Urine. This sign is present in **Diabetes-mellitus**. This disease is caused mainly due to less secretion of Insulin.

(ix) **Haematuria :-** Presence of blood in urine. It is a symptom of many diseases like black water fever, bacterial-infection.

(x) **Diuresis :-** The process of excess formation of urine in the kidney's is termed as diuresis.

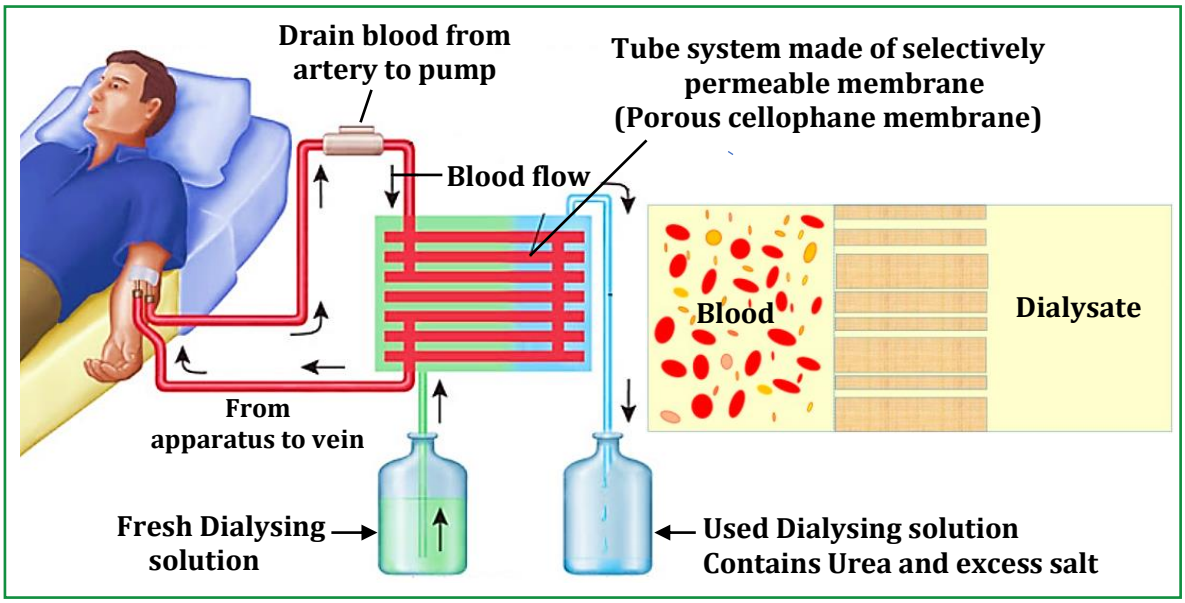
(xi) **Proteinuria :-** Presence of blood protein in urine.

(xii) **Albuminuria :-** Presence of albumin in urine, usually occurs in nephritis (inflammation of glomeruli), when the size of the filtering slits enlarges and basement membrane looses its negative charge.

(xiii) **Ketonuria :-** Presence of abnormally high ketone bodies in urine.

12. Hemodialysis :

- In **uremia patients**, urea can be removed by a process called **hemodialysis**. **Blood drained** from a convenient **artery** is pumped into a **dialysing unit after adding** an **anticoagulant** like **heparin**.
- The unit contains a **coiled cellophane tube** surrounded by a fluid **(dialysing fluid)** having the **same composition as that of plasma** except the nitrogenous wastes.
- The porous cellophane membrane of the tube allows the passage of molecules based on concentration gradient. As nitrogenous wastes are absent in the dialysing fluid, these substances freely move out, thereby clearing the blood.
- The cleared blood is pumped **back to the body through a vein after adding anti-heparin** to it. This method is a boon for thousands of uremic patients all over the world.


Drain blood from artery to pump
Tube system made of selectively permeable membrane (Porous cellophane membrane)
Blood flow
Blood
Dialysate
From apparatus to vein
Fresh Dialysing solution
Used Dialysing solution Contains Urea and excess salt

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Golden Key Points

- **(a)** The urine on standing gives a pungent smell. It is due to conversion of urea into ammonia by bacteria.
- **(b)** The volume of urine produced per day will increase on a cold day, due to ↓ADH secretion.
- Highest concentration of urea is found in hepatic vein. (because urea is synthesized in liver)
- Least concentration of urea is found in renal vein. (because urea is excreted through urine formed in kidney)
- If one kidney is removed, the remaining one enlarges and performs function of both kidneys.
- Camels can withstand water deprivation by reducing urinary water loss and water loss by sweat.
- Earthworms excrete ammonia when sufficient water is available while they excrete urea instead of ammonia in drier surroundings.
- When lung fishes and Xenopus (African toad) live in water, they are normally ammonotelic but they become ureotelic when they live in moist air or mud during summer.
- Crocodiles = normally ammonotelic
- **Bean shaped kidney** are present only in mammals.
- Uric acid is the last product of purine metabolism in human
- 2,6,8–trioxy purine is uric acid
- Inulin clearance can be used to Estimate GFR
- PAHA (Para Amino Hippuric Acid) clearance can be used to Estimate **RPF (Renal Plasma Flow)**
- Basement membrane is a meshwork of collagen and proteoglycan fibrils. It prevents filtration of plasma proteins because of strong negative charge present on it due to **proteoglycans.**
- In each kidney there are about 250 collecting duct each of which collects urine from 4000 nephrons.
- **Functions of kidney :**
  - Regulation of water and electrolyte balance.
  - Regulation of body fluid osmolarity and electrolyte concentration.
  - Regulation of acid base balance.
  - Regulation of arterial pressure.
  - Excretion of metabolic waste and foreign chemicals.
  - Secretion of hormones like erythropoeitin and renin.
- **Urinode** - Characteristic smell of the urine is due to urinode substances.
- Substances which are completely reabsorbed are called high threshold substances
  e.g. Glucose and Amino acid.
- Substances which are not reabsorbed at all are called Athreshold substances.
  e.g. Inulin, Creatinine, Para amino hippuric acid. (PAHA)
- Substances which are reabsorbed the body are demand of variable threshold substances.
  e.g. Electrolytes, water and urea.
- Substances which are less reabsorbed are called low threshold substances eg. Uric acid.
- Ions excreted out through urine are mainly monovalent ions eg. Na^+, K^+ Cl^-, HCO_3^-, H_3O^+ etc. where as ions removed out through faecal matter are mainly divalent and trivalent ions eg. Ca^{2+}, Mg^{2+}, CO_3^{2-}, PO_4^{3-}.
- Creatine :- In normal urine, creatine is absent. But in new-born infants, pregnant and lactating females the urine contains creatine. Creatine is obtained in the liver from amino-acids.
- Creatinine :- Creatinine is the break down metabolic product of creatine. It is formed in the muscles from high energy compound creatine phosphate. It is excreted along with urine.

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BEGINNER'S BOX-5

REGULATION OF KIDNEY FUNCTION, MICTURITION, ROLE OF OTHER ORGANS IN EXCRETION, HEMODIALYSIS AND DISEASES

1. The hormone that promotes reabsorption of water from glomerular filtrate is
(1) Oxytocin (2) Vasopressin (3) Relaxin (4) Calcitonin

2. Which regulates reabsorption of salts from Glomerular filtrate ?
(1) Oxytocin (2) Vasopressin
(3) Glucocorticoides (4) Mineralo corticoides

3. One is increased in blood of a person whose kidney is not working properly
(1) Urea (2) Ammonia (3) Sodium chloride (4) None

4. If kidneys fail to reabsorb water, the effect on tissue would
(1) Remain unaffected (2) Shrink and shrivel
(3) Absorb water from blood plasma (4) Take more O_2 from blood

5. A condition of failure of kidney to form urine is called -
(1) Creatinine (2) Hematuria (3) Anuria (4) Ketonuria

6. Presence of RBC in urine is called
(1) Anuria (2) Haematuria (3) Glycosuria (4) Ketonuria

7. Urine of a human being suffering from diabetes insipidus is
(1) Tasteless and thick (2) Sweet and thick
(3) Tasteless and watery (4) Sweet and watery

8. Kidney stone is produced due to
(1) Deposition of sand particles (2) Precipitation of proteins
(3) Crystallisation of oxalates (4) Blockage of fat

9. Diuresis is the condition in which
(1) The excretion of volume of urine increases
(2) The excretion of volume of urine decreases
(3) The kidney fails to excrete urine
(4) The water balance of the body is disturbed.

10. Excretory material are formed in
(1) Kidney (2) Rectum (3) Liver (4) Every body cell

11. Workers in deep mines usually suffer from dehydration because
(1) Water is lost due to micturition
(2) Water is lost due to defecation
(3) Water is lost in the form of urines
(4) Water is lost along with salts in the form of sweat

12. If Henle's loop were absent from mammalian nephron, which of the following is to be expected :-
(1) There will be no urine formation
(2) There will be hardly any change in the quality and quantity of urine formed
(3) The urine will be more concentrated
(4) The urine will be more dilute

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13. Which statement is false ?
(1) Nephrons perform excretion through filtration, reabsorption and secretion
(2) Nephridia are accessory excretory organs in Prawn
(3) Tapeworm have excretory flame cells
(4) Nephrons begin with Bowman's capsule having glomerulus

14. Vasa recta is minute vessel of peritubular capillaries network, which is
(1) Also known as juxta-glomerular apparatus
(2) Running parallel to loop of henle
(3) Running parallel to PCT
(4) Running parallel to DCT

15. The counter current mechanism operates in nephron
(1) In ascending and descending limb of vasa recta
(2) In ascending limb of Henle's loop
(3) In descending limb of Henle's loop
(4) Between the loop of Henle and vasa recta

16. The medullary gradient is mainly caused by
(1) NaCl and urea (2) H^+ and K^+ (3) Urea and K^+ (4) Urea and H^+

17. Human kidneys can produce urine nearly
(1) Three times concentrated than initial filtrate
(2) Four times concentrated than initial filtrate
(3) Ten times concentrated than initial filtrate
(4) Six times concentrated than initial filtrate

18. Aldosterone causes conditional reabsorption of ..... in the distal part of tubule.
(1) CO_2 (2) Ca^{2+} (3) Na^+ (4) Cl^-

19. ANF mechanism checks on
(1) Oxytocin-renin mechanism
(2) Counter-current mechanism
(3) Renin-angiotensin mechanism
(4) Oxytocin-angiotensin mechanism

20. Functioning of kindey is efficiently regulated by
(1) ANF (2) JGA (3) Both 1 and 2 (4) Lungs

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BEGINNER'S BOX ANSWERS KEY

BEGINNER'S BOX-1	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	2	3	2	3	3	2	4	3	1	3
	Que.	11	12	13							
	Ans.	2	3	4							

BEGINNER'S BOX-2	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	3	4	4	3	1	1	4	2	3	3
	Que.	11	12	13							
	Ans.	1	1	1							

BEGINNER'S BOX-3	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	3	1	2	3	4	2	4	1	3	2
	Que.	11	12	13	14	15	16	17			
	Ans.	1	1	1	4	3	2	4			

BEGINNER'S BOX-4	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	4	4	4	3	4	3	4	1	1	3
	Que.	11	12	13	14	15	16	17	18	19	20
	Ans.	3	4	2	2	2	3	3	1	3	3

BEGINNER'S BOX-5	Que.	1	2	3	4	5	6	7	8	9	10
	Ans.	2	4	1	2	3	2	3	3	1	4
	Que.	11	12	13	14	15	16	17	18	19	20
	Ans.	4	4	2	2	4	1	2	3	3	3

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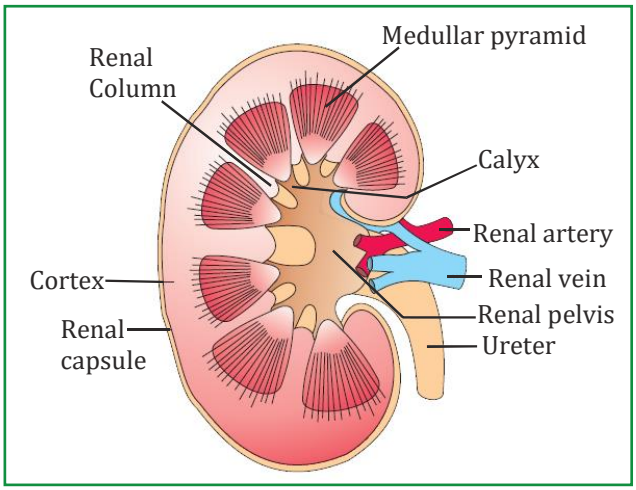
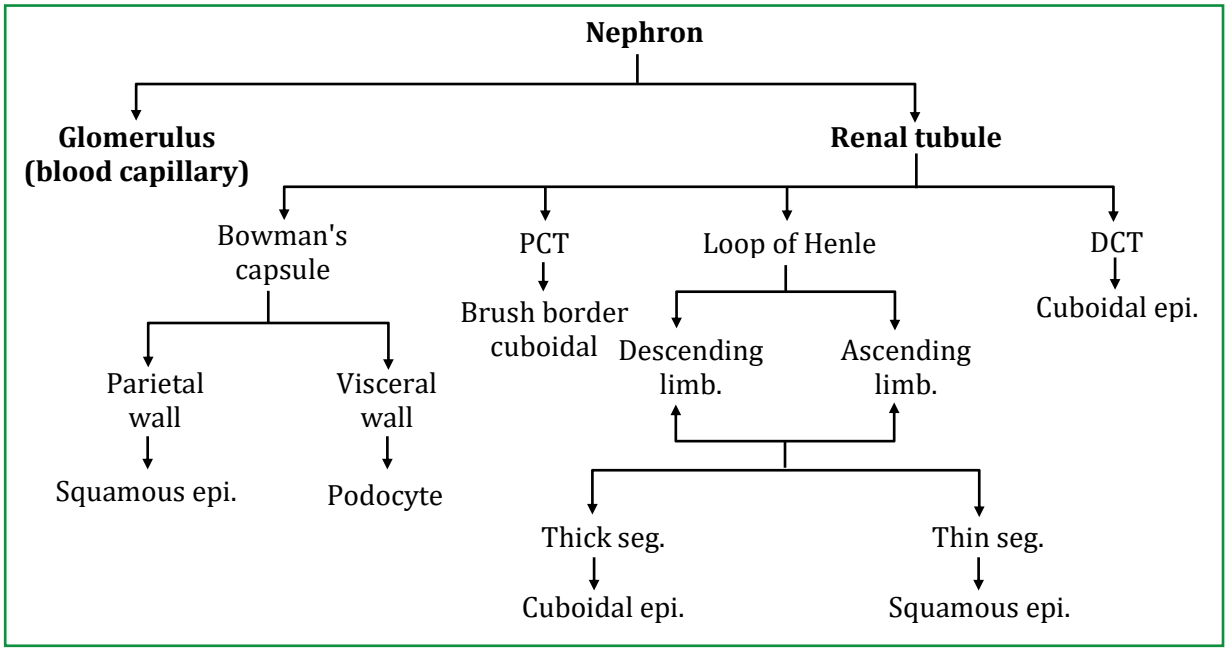
ESSENCE

- Major excretory products are ammonia (highly toxic), urea and uric acid (least toxic).
- Human excretory system consists of a pair of kidney a pair of ureters, a urinary bladder & a urethra.





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Mechanism of urine formation

Ultra filtration	Selective	Tubular
→ Filtration membrane has three layers. → GFR=125 ml/min. → Filtrate is protein less plasma	Reabsorption NaCl → PCT, AL of LH, DCT, CD H_2O → PCT, DL of LH, DCT, CD Nutrients – PCT HCO_3^- – PCT, DCT K^+ – PCT	H^+ – PCT, DCT, CD K^+ – PCT, DCT, CD NH_3 – PCT, DCT

- An adult human excrete on an average 1–1.5 L urine per day.
- 25–30 gm of urea is excreted out per day.
- Urine is slightly acidic, pH = 6.0
- Counter current mechanism is responsible for concentration of urine, in which loop of Henle & Vasa recta play role.
- Concentration gradient in cortex is 300 mosmol/L, which goes to 1200 mosmol/L in medulla and is maintained by NaCl and urea.
- Osmoreceptors in body upon activation send signals to hypothalamus for release of ADH.

Angiotensinogen $\xrightarrow{\text{Renin}}$ Angiotensin I $\xrightarrow{\text{ACE}}$ Angiotensin II.

Angiotensin II → Aldosterone from adrenal cortex

Angiotensin II → Vosoconstriction ↓ B.P. ↑

- High B.P. ⟶ ANF from atria of heart vasodilation → B.P. ↓
- Myogenic mechanism cause constriction of afferent arteriole.
- Signals for micturition starts from stretching of urinary bladder
- For micturition, voluntary signal is given by CNS.
- Human lungs eliminate about 200 ml/min. CO_2.
- Human lungs eliminate about 400 ml/day water.
- In skin, sweat glands & sebaceous glands help in excretion.
- Liver remove cholesterol, Bile pigments, degraded steroid hormones, some vitamins and drugs.
- Accumulation of urea in blood is called uraemia.
- In patients of uraemia, urea can be removed by haemodialysis.
- Kidney transplantation is ultimate method in the correction of renal failures.
- Glomerulonephritis is inflammation of basement membrane of glomerulus.
- Renal calculi is formation of kidney stones, made up of calcium oxalate.